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Addendum

FINAL REPORT OF REVERSE OSMOSIS APPRAISAL PROGRAMS AT FURNACE CREEK AND STOVE PIPE WELLS IN DEATH VALLEY NATIONAL MONUMENT

by

R. L. Truby

Prepared under
Contract 14-10-4:940-165
for the
National Park Service
U.S. Department of the Interior

June 11, 1970

Gulf General Atomic
Incorporated
P.O. Box 608, San Diego, California 92112

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ABSTRACT

Reverse osmosis field demonstrations have been conducted in the Village Park area of Furnace Creek and at Stove Pipe Wells in Death Valley National Monument. The purpose of these demonstrations was to illustrate the ability of reverse osmosis to produce potable water from the existing spring and well water supplies. A trailer-mounted reverse osmosis unit capable of producing 4000 gpd of high-purity potable water was utilized for these demonstrations.

The demonstration unit was initially operated for two days at Village Park. During this period the spring water processed by the unit was reduced in total dissolved solids content by more than 96%. This reduction included the lowering of fluoride and calcium carbonate concentrations to safe levels.

The demonstration unit was then operated for two days on the brackish well water at Stove Pipe Wells. At this location the water produced by the unit was reduced in total dissolved solids content by more than 94%. This previously undrinkable well water was thus converted into an immediately available potable source.

In this report, the results of the field demonstrations are presented, and the basic requirements and economics of reverse osmosis are discussed. Based on these considerations, a 200,000-gpd reverse osmosis unit is recommended as a solution to the water treatment problems at Village Park. This unit would produce high-purity potable water at an estimated cost of 87¢/1000 gal. For Stove Pipe Wells, a 50,000- to 70,000-gpd unit is recommended. The cost of potable water produced by this unit is estimated at $1.07/1000 gal.

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1. INTRODUCTION

A series of reverse osmosis* field demonstrations has been carried out by Gulf General Atomic Incorporated (GGA) for the National Park Service, U.S. Department of the Interior, under Contract 14-10-4:940-165. This report describes the results of demonstrations carried out at Furnace Creek and Stove Pipe Wells in Death Valley National Monument. The results of previous tests conducted at Chaco Canyon National Monument and Petrified Forest National Park have already been reported.**

The original impetus for this program of field demonstrations came from G. S. Witucki, Chief of Water Resources Section, Western Service Center, National Park Service. The main purpose of the program is to determine the feasibility of converting existing substandard*** spring and well water supplies to potable water sources by using reverse osmosis.

Utilization of reverse osmosis has numerous advantages over other potential methods of acquiring potable water (i.e., importation by truck or pipeline) in the relatively dry southwest United States and elsewhere. Some of the more important advantages are:

1. <u>Maximum Utilization and Conservation of Available Water</u>
   Importation of potable water by truck or pipeline offers an immediate solution to the water shortage problem in any area. However, as the demand increases, the supply of untreated potable water can be expected to rapidly disappear. Reverse osmosis offers the capability of converting substandard brackish water supplies, and water supplies declared unsafe by the U.S. Public

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*See Appendix A for a description of reverse osmosis.

**Poole, G. F., and R. G. Sudak, "Final Report of Reverse Osmosis Appraisal Programs at Chaco Canyon, New Mexico, and Petrified Forest, Arizona," Gulf General Atomic Report GA-9860 (Rev.), December 1969.

***See Appendix B for U.S. Public Health Service Standards.

Health Service, into immediately available potable sources. In addition, reverse osmosis can be applied to already potable water sources in such a way as to reduce problems, i.e., high calcium carbonate and fluoride concentrations. Thus, the net effect of using reverse osmosis would be maximum utilization of the water supply in an area.

2. Flexibility for Expansion

   The use of reverse osmosis offers flexibility in that the amount of potable water produced by a unit can easily be expanded with the demand for it. This is, of course, subject to the limitation of the raw water supply. The increase in the production of a unit is accomplished merely by adding the necessary number of ROGA® modules (each capable of producing 400 gpd of high-purity potable water) and increasing the pump capacity. This flexibility for expansion has the obvious advantage of allowing areas of accelerated growth to rapidly respond to public demand.

3. Preservation of Ecological Stability

   Reverse osmosis divides a local natural water supply into two parts: a large potable stream low in dissolved solids, and a smaller concentrate (brine) stream containing most of the solids and particulate matter. These two streams could be recombined in the waste disposal system. Since little is added or extracted from the total, the effect is the same as if the local water supply were used without treatment. The local water is already in use at both Furnace Creek and Stove Pipe Wells. Consequently, the use of reverse osmosis to supply the needs of the people in these areas would have little if any further effect on the ecology of the area.

These important steps toward the conservation of both water and the ecological system are good reasons for considering reverse osmosis as a potential means of securing a potable watter supply. The results of the

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two field demonstrations described in this report are specific examples of how substandard water supplies can be converted to potable water sources.

The field demonstrations conducted in Death Valley National Monument were carried out from March 31 to April 6, 1970. During this period data from more than four days of continuous operation were gathered. The results of these tests and the economics of reverse osmosis systems capable of solving the specific problems in Death Valley are the major concern of this report.

2. DESCRIPTION OF DEMONSTRATION UNIT

The trailer-mounted 4000-gpd reverse osmosis unit utilized for these demonstrations is shown in Fig. 1. Its components and size rating follow the same standards and guidelines as all commercial and Government reverse osmosis units sold by GGA. This demonstration unit serves the dual purpose of giving interested parties a first-hand view of reverse osmosis and at the same time allowing GGA to realistically project the performance of a commercial unit operating on the local water.

The demonstration unit consists of pretreatment equipment, high-pressure pumps, and nine spiral-wound reverse osmosis modules contained in three pressure vessels. The pretreatment equipment is comprised of two chemical addition pumps, two full-capacity cartridge filters capable of removing particulate matter larger than 10 μ from the feedwater, a pH controller, and a 50-gal tank, complete with mixer, for addition of extra chemicals. One of the chemical addition pumps is automatically operated by the pH controller and adds the correct amount of acid to maintain a feedwater pH of approximately 5.0 to 6.0. The second chemical addition pump is used for injection of chlorine and/or sodium hexametaphosphate into the feedwater. When one or both of these chemicals are added, they are mixed and stored in the 50-gal tank.

After pretreatment, the feedwater is pressurized by two in-series multistaged submersible centrifugal pumps. These pumps require 230-V, three-phase power and are capable of delivering 6 gpm at a pressure of 500 psi. The pressurized feedwater is manifolded into the first two pressure vessels, which are in parallel. The brine from these two vessels is collected and utilized as the feedwater for the third vessel. The product water from all three vessels is combined and discharged through one hose, while the brine is discharged through another. A schematic diagram of the entire system is shown in Fig. 2.

Fig. 1. Trailer-mounted, 4000-gpd reverse osmosis demonstration unit

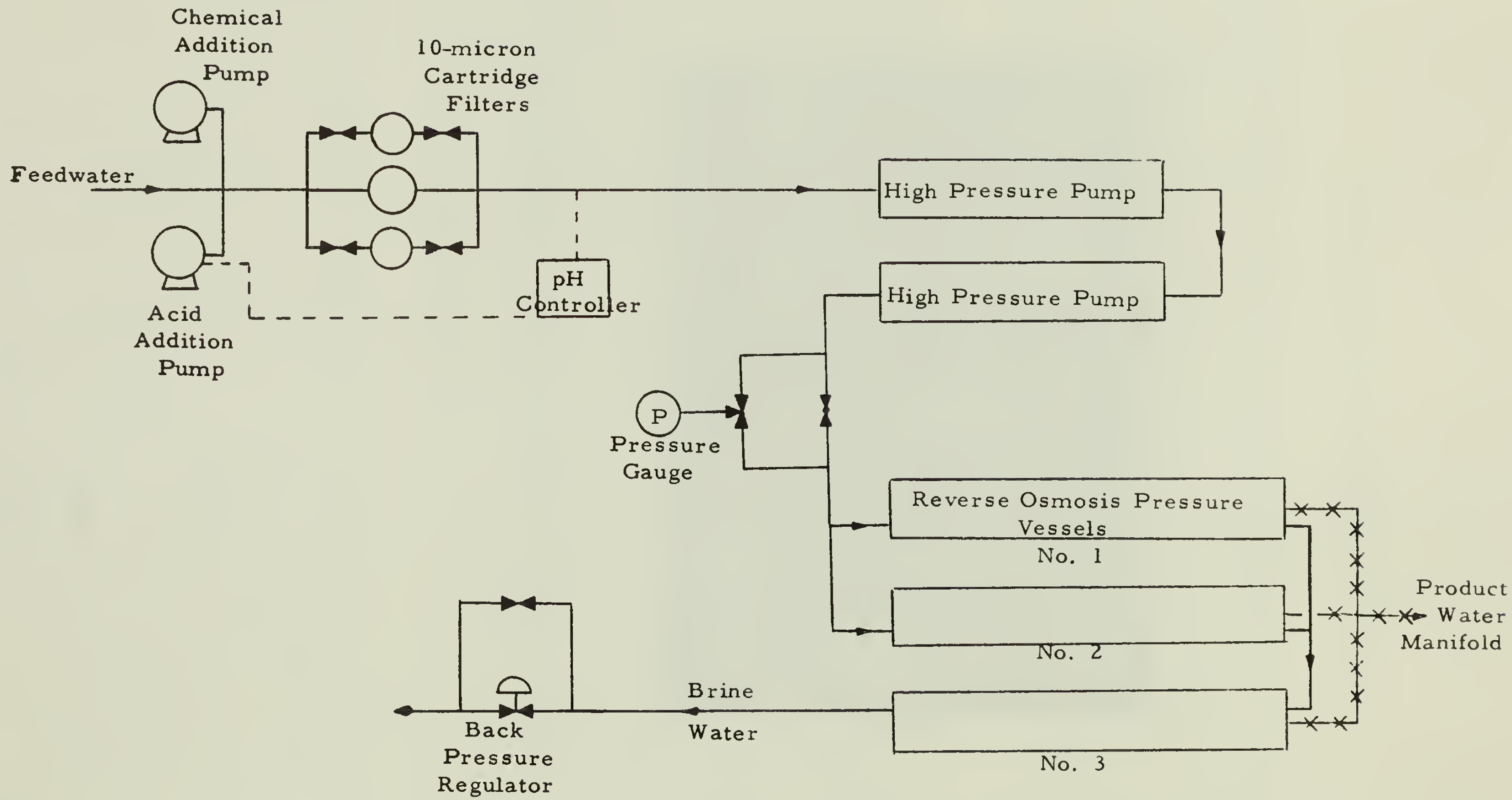

Fig. 2. Schematic of reverse osmosis demonstration unit

The modules contained in the three pressure vessels are standard Model 4000 ROGA spiral-wound modules, each having a nominal membrane area of 50 ft^2. The spiral-wound module is shown diagramatically in Figs. 3 and 4, while Fig. 5 shows the modules installed in a pressure vessel.

The pressure at which the unit is operated and the flow scheme of the feedwater combine to yield 4000 gpd of product water at 77°F and 50% recovery (1 out of every 2 gal of feedwater recovered as high-purity product water). The recovery of this system is limited by the exit brine flow, which should be in excess of 2.5 gpm to lessen the effects of concentration polarization. Units with 10,000-gpd capacity and greater are designed to operate at 75% recovery (3 out of 4 gal recovered as product water), thus offering increased efficiency. Higher recoveries are attainable and can be provided for in the unit design. The optimum recovery at which a unit can be operated ultimately depends on the feedwater composition and the unit size.

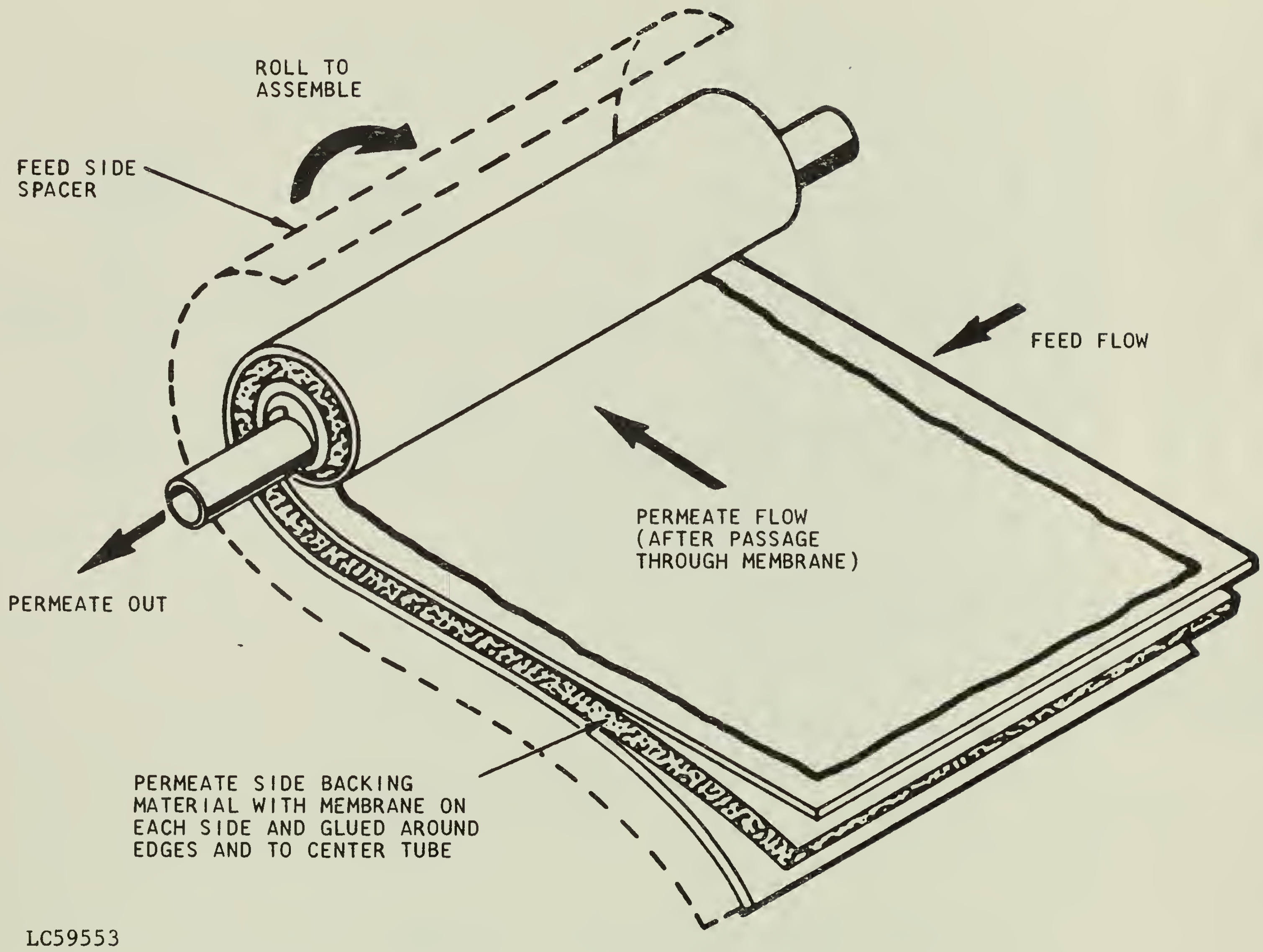

Fig. 3. Spiral-wound module concept

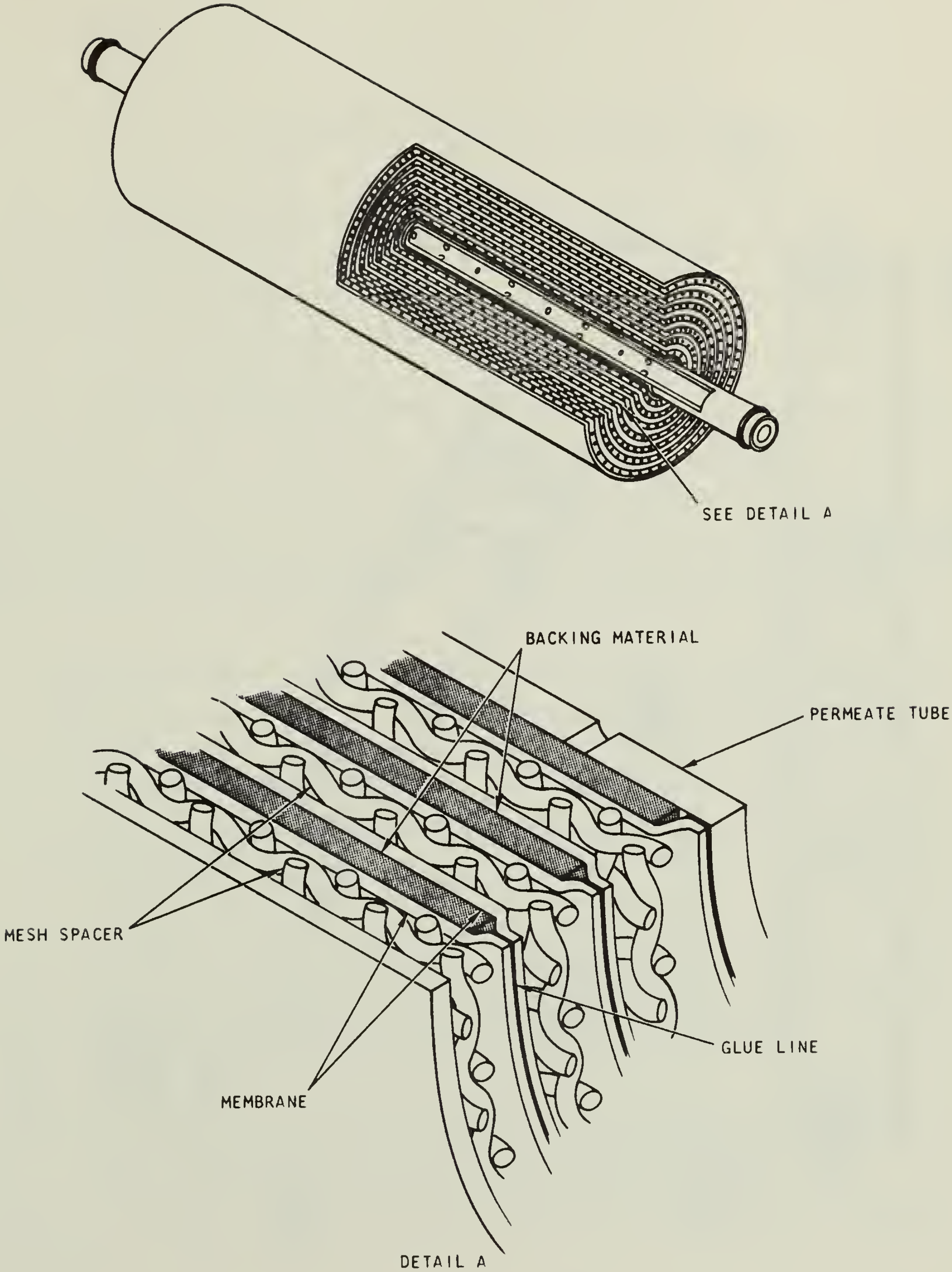

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Fig. 4. Spiral-wound module cutaway

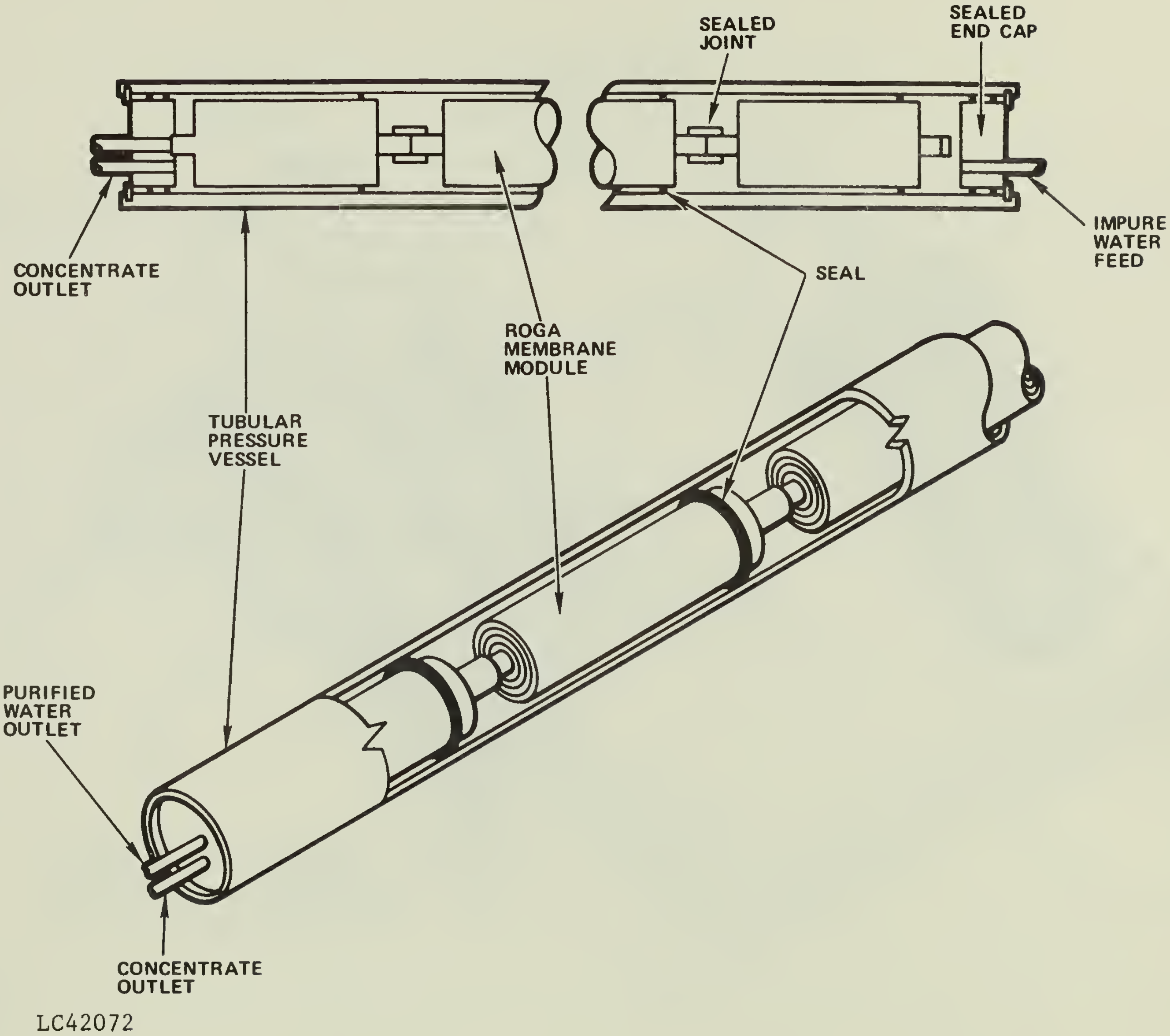

Fig. 5. Module orientation in pressure vessel

3. PERFORMANCE OF UNIT AT FURNACE CREEK

The demonstration unit and two GGA representatives arrived at Furnace Creek on March 31. The unit was immediately taken to a predetermined site in the National Park Service Residence and Utility Area. This location is referred to as Village Park (see Fig. 6).

The water currently utilized in this area is piped in from Cow Spring, a short distance away. Before the water is piped to the utility area, irrigation ditches, and individual homes, it is passed over a cooling tower and collected in a large storage tank (see Fig. 7). The two major problems arising from utilization of this spring water are:

1. Precipitation of travertine (calcium carbonate hardness), causing maintenance problems with evaporative coolers and the plumbing system

2. High fluoride content (characteristically 7 ppm), causing damage to children's teeth

The fluoride level is currently controlled by a type of filtration. The travertine deposition is being dealt with by mechanically scraping it from the evaporative coolers and replacement of the plumbing.

The field demonstration was conducted on the spring water prior to removal of excess fluoride. This enabled both Park Service and GGA personnel to determine the unit's effectiveness in lowering the fluoride and travertine concentrations.

At 0930 April 1, the demonstration unit was put into operation. It operated continuously until 1030 April 3; then, according to schedule, it

Fig. 6. Trailer-mounted, 4000-gpd reverse osmosis unit at Village Park, Furnace Creek. Left to right: Alan 3. Riedinger (GGA), Harold Grineer (National Park Service), and Milo Bonifield (Maintenance Superintendent, National Park Service)

Fig. 7. Cooling tower and storage tank at Village Park

was moved to Stove Pipe Wells. During the 49 hr of operation at Village Park, 17,120 gal of spring water were treated; 8360 gal were recovered as high-purity product water, leaving 8760 gal of concentrate. This is equivalent to 49% recovery, or almost 1 out of every 2 gal converted to high-purity water.

Measurements were taken at least twice daily of pressure, flow, pH, temperature, and conductivity. These data are given in Table 1. In addition, samples of the raw spring water; spring water after addition of acid, chlorine, and sodium hexametaphosphate; product water; and brine were collected and returned to San Diego for analysis by an independent laboratory. The results of these analyses appear in Table 2.

As stated above, acid, chlorine, and sodium hexametaphosphate were continuously added to the spring water prior to exposure to the reverse osmosis membrane. A small amount of sulphuric acid was added to adjust the spring water pH, which is characteristically 8.0, to approximately 5.5. This step prevents the precipitation of calcium carbonate and also extends the life of the membrane. Chlorine was added at a rate of 0.5 ppm residual to protect against possible biological attack. Sodium hexametaphosphate was added at a rate of 5 ppm to prevent precipitation of sparingly soluble salts, such as calcium sulfate. The cost of this chemical addition is low compared with the benefits derived (this subject is discussed in Section 6).

As can be seen from Tables 1 and 2, the product water was of excellent quality. The dissolved solids content of the product water had been reduced by more than 96%; the travertine in the product water was far below the saturation level, which meant that no deposition would occur; and the fluoride level was well within the maximum limit of 0.8 ppm recommended by the U.S. Public Health Service (see Appendix B).

The ease with which this high-quality water was produced, the compact nature of the equipment, and the flexibility for expansion make reverse osmosis an attractive method of solving the water problems at Village Park.

TABLE 1

VILLAGE PARK OPERATING DATA

Date	4-1	4-1	4-1	4-2	4-2	4-2	4-3
Time	1015	1330	1635	0835	1400	1700	0910
Pressure, psi	470	470	480	450	470	470	470
Temperature, ^{o}C	23	25	24	22	25	25.5	24.5
Feed Conductivity, μmho/cm	1055	1030	1093	1035	1080	1095	1066
Brine Conductivity, μmho/cm	2270	2290	2260	1870	2120	2160	2010
Product Conductivity, μmho/cm	53.4	52.3	58.6	58.7	64.0	61.5	60.2
Feed pH	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Product Flow, gpm	3.33	3.33	3.25	2.80	3.10	3.05	2.8
Brine Flow, gpm	2.44	2.44	2.60	3.25	2.80	2.80	3.0
Rejection, %	96.8	96.8	96.5	96.0	96.0	96.2	96.1

TABLE 2

CHEMICAL ANALYSIS -- VILLAGE PARK, COW CREEK SPRING WATER[a]

	Raw Spring Water	Acidified Spring Water	Brine	Product
Calcium (Ca)	40	48	96	1.2
Magnesium (Mg)	20	17	46	0.4
Sodium (Na)	155	150	300	10
Potassium (K)	11	11	21	0.6
Carbonate (CO_3)	0	0	0	0
Bicarbonate (HCO_3)	344	61	122	12
Sulfate (SO_4)	185	407	800	4
Chloride (Cl)	45	45	95	8
Nitrate (NO_3)	0.10	0.10	0.19	0.05
Boron (B)	1.0	1.0	1.2	0.7
Fluoride (F)	6.5	6.5	11	0.54
Silica (SiO_2)	32	30	70	1.9
Iron (Fe)	0	0	0	0
Manganese (Mn)	0	0	0	0
Ortho Phosphate (PO_4)	0.02	0.15	0.39	0
Total Dissolved Solids				
105° C	646	744	1482	40
185° C	632	708	1432	24
pH	8.0	6.1	6.6	5.5
Specific Conductivity				
μmho/cm at 25°C	1070	1070	2200	60

[a]Results in mg/l except where noted.

A thorough and more specific set of recommendations and cost estimates pertaining to the possible utilization of reverse osmosis at Village Park is presented in Sections 5, 6, and 7.

4. PERFORMANCE OF UNIT AT STOVE PIPE WELLS

On April 3, the demonstration unit was disconnected at Village Park and moved to Stove Pipe Wells (approximately 30 miles away). The planned site of operation was adjacent to the brackish well currently supplying part of the water for the Stove Pipe Wells Village. However, this site proved to have insufficient electrical power, and the unit was moved into the motel area. At 1600 April 3, the unit was put into operation using the brackish well water flowing from a fire plug near the motel restaurant (see Fig. 8).

The Stove Pipe Wells Village is currently on a dual water system. Potable water is imported from Furnace Creek and Immigrant Springs by truck and stored in a tank. This water is then piped to various outlets marked for drinking only. The water taken from the brackish well is piped to the individual motel rooms for uses other than drinking. The brackish well water has a total dissolved solids content of around 3000 ppm, with large amounts of sodium chloride and sulfate. The fluoride content is characteristically 5 ppm and consequently higher than the U.S. Public Health Service permits. Obviously, its high salinity, high fluoride content, and poor taste render this water unsuitable for consumption.

After startup, the demonstration unit operated continuously with the exception of one brief shutdown (estimated at less than 1/2 hr), believed to be caused by a momentary electrical power loss. At 1500 April 5, the test was terminated and the unit was prepared for transport back to San Diego. During the 47 hr of operation at Stove Pipe Wells, 14,460 gal of well water passed through the unit; 6950 gal were recovered as potable product water, leaving 7510 gal of concentrate. This is equivalent to 47% recovery. The slightly lower recovery as compared with operation at Village Park can be attributed to the lower operating pressure and higher osmotic pressure of the feedwater.

Fig. 8. Reverse osmosis unit at Stove Pipe Wells (attended by David Chavez, National Park Service)

Acid, chlorine, and sodium hexametaphosphate were added to the well water just as they had been at Village Park. Measurements were again taken twice daily and are presented in Table 3. Samples were also collected and returned to San Diego for analysis. The results of these analyses appear in Table 4.

The information presented in Tables 3 and 4 illustrates the excellent quality of the product water produced during this demonstration. The dissolved solids content of the product water was reduced by more than 94%; both the sodium chloride and sulfate concentrations were reduced to safe levels; and the fluoride content was well below the U.S. Public Health Service suggested maximum of 0.8 ppm.

At Village Park it was clearly demonstrated that reverse osmosis could successfully treat a potable water supply in such a way as to minimize problems. The field test at Stove Pipe Wells illustrates the ability of reverse osmosis to take a substandard water supply and convert it into a readily available potable source. The economics of this conversion process and recommendations as to possible methods of utilization are discussed in Sections 5, 6, and 7.

TABLE 3

STOVE PIPE WELLS OPERATING DATA

Date	4/3	4/4	4/4	4/5	4/5
Time	1630	0740	1630	0825	1515
Pressure, psi	400	400	400	400	400
Temperature, $^{\circ}$ C	28.5	26.5	29	26	30
Feed Conductivity, μmho/cm	5020	4640	5020	4700	5230
Brine Conductivity, μmho/cm	8930	8280	9050	8520	9620
Product Conductivity, μmho/cm	424	355	377	344	408
Feed pH	5.5	5.5	5.5	5.5	5.5
Product Flow, gpm	2.50	2.45	2.40	2.35	2.40
Brine Flow, gpm	2.85	2.60	2.90	2.70	2.50
Rejection, %	93.9	94.5	94.6	94.8	94.5

TABLE 4

CHEMICAL ANALYSIS -- STOVE PIPE WELLS[a]

	Raw Well Water	Acidified Well Water	Brine	Product
Calcium (Ca)	136	136	270	16
Magnesium (Mg)	78	78	151	4.9
Sodium (Na)	780	750	1420	67
Potassium (K)	50	53	105	5.4
Carbonate (CO_3)	0	0	0	0
Bicarbonate (HCO_3)	403	110	207	24
Sulfate (SO_4)	406	650	1254	4.9
Chloride (Cl)	1210	1250	2250	91
Nitrate (NO_3)	0.10	0.18	0.35	0.04
Boron (B)	6.2	6.2	7.6	4.9
Fluoride (F)	5.0	5.0	9.5	0.2
Silica (SiO_2)	60	55	130	5.2
Iron (Fe)	0.16	0.04	0.08	0
Manganese (Mn)	0	0	0	0
Ortho Phosphate (PO_4)	0	0.17	0.41	0.04
Total Dissolved Solids				
105° C	2928	3052	5692	216
185° C	2836	2912	5524	188
pH	7.3	6.3	7.6	5.7
Specific Conductivity μmho/cm at 25°C	4900	5000	9200	340

[a] Results in mg/l except where noted.

5. REVERSE OSMOSIS APPLICATION IN DEATH VALLEY

The field tests described in Sections 3 and 4 clearly demonstrate the ability of reverse osmosis to successfully treat the existing spring and well water supplies in Death Valley. In this section, some of the basic requirements for a reverse osmosis system and some of the application options available are discussed, with emphasis on exploration of potential problems and suggested solutions.

BASIC REQUIREMENTS

At both Village Park and Stove Pipe Wells, it would be necessary for the purchaser of a reverse osmosis unit to provide the following:

1. Electrical Power Supply. A 460- or 230-V, three-phase, 60-cycle power source is required for operation of the high-pressure pump. In most cases, a 460-V power source offers the advantage of a lower installation cost. A 110-V, one-phase, 60-cycle power source is needed for operation of ancillary equipment.

2. Unit Support and Protection from the Elements. The unit should have a concrete slab to support it. In addition, some type of protection from the hot summer sun should be provided. This protection could consist of a building, or poles and a roof.

3. Unit Maintenance. Field service assistance is available from GGA in San Diego in case of emergencies. However, day-to-day unit maintenance is the responsibility of the purchaser. Such maintenance includes back-flushing of sand filters, purchase and addition of pretreatment and post-treatment chemicals,

changing of cartridge filters, membrane cleaning procedures (if required), and monitoring of unit performance on at least a once-daily basis. These tasks should require less than 1 hr per day for one operator. Emergency shutoff devices are included in all units, and automatic startup and shutdown can be included so that 24-hr operation causes no special manpower problems.

All of these responsibilities of the purchaser are clearly explained in the operating manual supplied with each unit. In addition, GGA personnel provide on-site training during unit installation.

4. Pretreatment and Post-Treatment of Product Water. As discussed in Sections 2, 3, and 4, the addition of acid, sodium hexametaphosphate, and chlorine is a necessary pretreatment step. The responsibility for the purchase and addition of these chemicals is entrusted to the purchaser. The necessary pumps, fittings, and tanks are supplied by GGA.

   Post-treatment of the product water will probably also be necessary because of the addition of acid to the feedwater. When the feedwater pH is adjusted to approximately 5.5, as it should be for almost all applications, carbon dioxide is formed and remains in solution. Some of this carbon dioxide passes through the membrane into the product water and lowers its pH. As a result, some method of post-treating the product water will be required to raise the pH and stabilize the product. There are several methods of accomplishing this, such as decarbonization, degasification, or treatment with limestone or soda ash. The cost of this treatment is minimal and is discussed in Section 6.

5. Water Temperature Control. The membrane used in reverse osmosis systems is temperature-sensitive. A graph illustrating the effect of temperature on product water flow is presented in Fig. 9. At

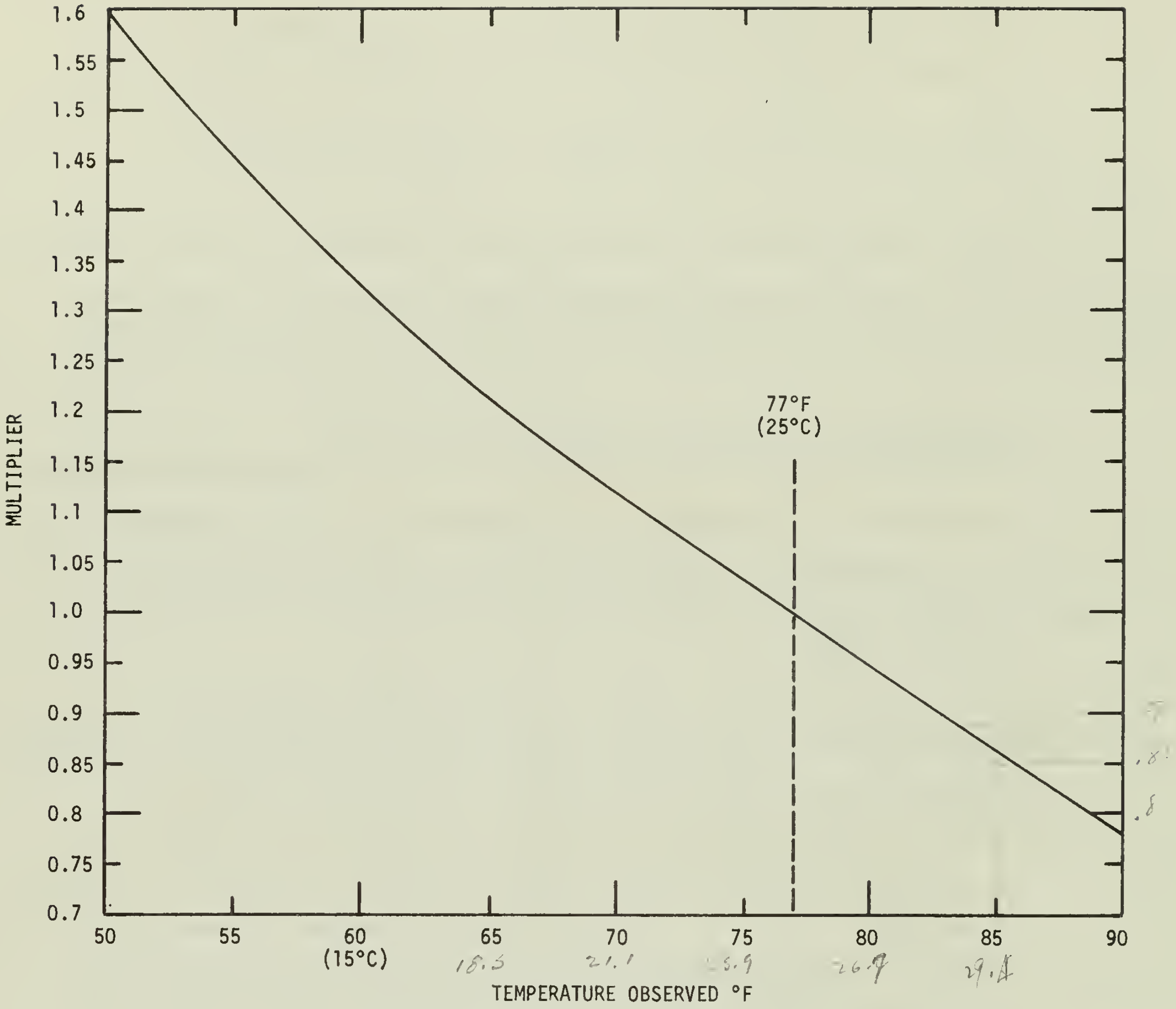

Fig. 9. Dependence of water flux on temperature; for values other than 77°F (25°C), use appropriate multiplier

feedwater temperatures above 85°F, the membrane compacts at a faster than desirable rate. This compaction is essentially irreversible, and while it may have no noticeable short-term effect, it will hinder long-term membrane performance.

The problem most likely to be encountered with reverse osmosis application at Death Valley is high water temperature. This can best be handled by locating the reverse osmosis unit downstream of the cooling tower at Village Park, and adjacent to the well at Stove Pipe Wells. It is believed that both of these locations deliver water at acceptable temperatures throughout the year.

APPLICATION OPTIONS AT VILLAGE PARK

The current water usage at Village Park is not exactly known. For the purpose of this discussion, the figure of 175 gpm, or 250,000 gpd, will be used. This is the amount of water estimated to flow out of the spring, over the cooling tower, and into the storage tank. The amount of water required by the residents and in the utility area is drawn from the storage tank, while the excess vents through an overflow and is used for open ditch irrigation. During the winter months, from October until May, approximately 80% to 90% of the spring water flows through the overflow. In the summer months, little water flows through the overflow owing to the increased demand for water by the residents for use in evaporative home coolers and a swimming pool.

what time of year

The waste disposal system at Village Park is an open lagoon. At peak periods during the winter this lagoon occasionally overflows.

There are three possible ways by which reverse osmosis might be utilized to solve the water treatment problems at Village Park:

1. Installation of a large reverse osmosis unit for treatment of the entire water supply used in the area

2. Installation of a dual plumbing system: one system using reverse osmosis to treat water for drinking and the evaporative coolers, and the other system for sprinkler irrigation, the swimming pool, etc.

3. Installation of individual home reverse osmosis units

The first alternative listed above would require one reverse osmosis unit large enough to handle the peak usage period. As stated previously, this occurs during the summer months and involves approximately 200,000 gpd of product water. A unit of this capacity would require a concrete slab and cover approximately 34 ft x 15 ft x 10 ft. If the unit were located just downstream of the cooling tower, water temperature problems should not arise. The product water could then be piped directly into the storage tank. This would allow automation of the unit to the extent that it would shut down when the tank was full and start up when the tank reached a predetermined level. The existing plumbing system would be adequate for distribution of the product water. While the unit was shut down, the raw spring water could be diverted into the open ditch irrigation system, and consequently the plant life should not be affected.

If this unit were designed to operate at 75% recovery, it would produce approximately 60,000 gpd of brine during peak summer periods. The salinity of this brine would be around 3000 ppm, assuming a constant spring water concentration, which would include approximately 600 ppm sodium, 190 ppm chloride, 1600 ppm sulfate, and 2.4 ppm boron. It is difficult to say whether or not this water would be suitable for open ditch irrigation without knowledge of soil characteristics, drainage, and number of plants. Preliminary evaluation suggests that the sodium chloride and boron levels would be rather high. However, the plants and trees to be irrigated (such as the date palm) are extremely salt-tolerant. Before the brine is utilized for irrigation, it is suggested that a qualified person be consulted.

An alternative method of brine disposal is through the existing waste disposal system. This approach would require installation of a pipeline or open ditch to transport the brine to the lagoon. The lagoon would probably need to be enlarged to handle the current overflow, plus that amount of brine produced by the reverse osmosis unit. Around 10,000 gpd of brine would be produced during the winter months, when the lagoon overflow problem occurs. During the summer months, a larger quantity of brine would be produced; however, evaporation would also occur at a faster rate.

The second option presented above would require determination of what the minimum product water needs would be. Drinking water and water for the evaporative coolers are two essential uses. Sprinkler irrigation obviously is not. After this determination had been made, a reasonable plumbing system would have to be installed.

The reverse osmosis unit would still be best situated near the cooling tower because of the potential water temperature problems. Automatic operation and brine disposal could be handled in the same way as described for a larger unit. A slab and cover would still be required.

As can be seen, the reverse osmosis unit would really change only in size. The major factor here is the economics of installing the additional plumbing, which, of course, would have to be determined by the purchaser.

The third alternative is individual home reverse osmosis units. These would be used to produce good-quality water for the evaporative coolers and drinking water. It is difficult to say how much water the coolers require. For the purpose of discussion, it is assumed that each home reverse osmosis unit would need to be about 200 to 500 gpd in size.

The use of home units would require installation of enough plumbing to supply the product water to the coolers, plus the desired drinking water outlets in each home. This approach would necessitate installation

of a small storage tank to handle the irregular demand. In addition, the necessary pumps and pretreatment equipment would have to be installed with each unit.

A potential problem with home units might be water temperature. Because of high ground temperatures during summer months, transporting water any distance downstream of the cooling tower results in a significant increase in the temperature of the water in the plumbing. This problem can be combated by burying the pipes deeper or by piping the feedwater through the cooling units at each home. This constitutes the major difference between alternatives 2 and 3. The second alternative treats all the water at once. Consequently, the pretreatment and post-treatment chemicals are added at one spot, and the unit can be located near the cooling tower to obtain the most acceptable water temperature. These advantages are lost with home units. In addition, each home unit would require approximately the same amount of maintenance as one larger unit.

Gulf General Atomic does not directly market units smaller than 25,000 gpd, other than on a pilot plant basis, and consequently cannot quote prices on units in the 200- to 500-gpd size range. The companies that do, or might, distribute reverse osmosis units in the size range desired are listed below:

Ajax International Corporation
P. O. Box 4007
Santa Barbara, California 93103

Culligan, Inc.
1657 South Shermer Road
Northbrook, Illinois 60062

Layton Soft Water, Inc.
502 S. Lyon Street
Santa Ana, California 92701

Polymetrics
810 Cherry Lane
San Carlos, California 94070

APPLICATION OPTIONS AT STOVE PIPE WELLS

The Stove Pipe Wells area is currently operating on a dual water system. Potable water is imported by truck and stored in a tank. The estimated daily

usage is 1000 to 2000 gal, most of which is used for drinking and cooking. The water taken from the brackish well in the area is utilized for all other purposes, and amounts to approximately 60,000 gpd during peak periods.

Waste disposal is accomplished by septic tank. This system may currently be exceeding its capacity, and it has been suggested that a lagoon will be built.

Two possibilities are evident for utilization of reverse osmosis at Stove Pipe Wells:

1. Installation of a large reverse osmosis unit to provide all necessary water

2. Installation of a reverse osmosis unit sized to produce the necessary quantity of potable water, and retention of the dual system

The first alternative would require installation of a 50,000- to 70,000-gpd reverse osmosis unit. A unit of this capacity would necessitate a concrete slab, and cover approximately 34 ft x 8 ft x 7 ft. The unit should be located near the well to ensure a reasonable water temperature throughout the year. The product water would then be piped into the storage tank and distributed through the existing well water plumbing system. This system currently reaches all rooms in the motel area and should require no additional plumbing. If necessary, a portion of the product water could be directed into the existing potable-water-only system, in which case all the existing plumbing and outlets would be utilized.

The only method of brine disposal is through the waste system. As stated above, this system may already be at its limit. If a lagoon is to be built, it could be designed to handle the additional 20,000 gpd of brine produced during peak periods by the reverse osmosis unit without prohibitive additional expense.

The second possibility listed above would require installation of a 1000- to 2000-gpd reverse osmosis unit. This unit should also be located near the well, and would entail all the stipulations made for a larger unit. The product water could be piped into the existing tank for distribution. Gulf General Atomic does not market units of this size. The list of suppliers presented in the discussion of Village Park also applies in this case.

It should be pointed out that if camping facilities at Stove Pipe Wells are expanded, an additional supply of potable water will be required. Reverse osmosis can easily be applied in such a way that the necessary quantity of potable water for the entire area can be provided by one central unit and a suitable plumbing system. The first step would be to determine the combined water usage in the camping area and the Stove Pipe Wells Village. In this way, the correct size unit can be determined. A price can then be extrapolated from Tables 5, 6, and 7 in Section 6 of this report.

6. THE ECONOMICS OF REVERSE OSMOSIS

The previous sections in this report have dealt with demonstrating the ability of reverse osmosis to successfully treat the waters at Furnace Creek (Village Park) and Stove Pipe Wells and possible means of application. This section deals with the economics of reverse osmosis.

A number of reverse osmosis units are currently being produced and placed in operation. These range in size from 3 to 125,000 gpd, and designs are complete for even larger units. This situation makes it possible to project realistic estimates of the capital and operating costs associated with reverse osmosis units over a broad spectrum of sizes. Since the heart of any reverse osmosis system is the module, it is possible to "scale up" in projecting costs of reverse osmosis systems with almost no risk of error.

The factors contributing to the cost of reverse osmosis water treatment are discussed in some detail below, and typical data on capital and water costs are presented as a function of unit size. These data are sufficiently valid to be used with confidence in performing a screening evaluation of the current state of the art. Data are also presented which project advances in reverse osmosis that will almost surely occur over the next few years. Thus, an envelope of present and future costs can be developed in considering possible applications.

OPERATING COSTS

The operating costs of reverse osmosis systems are as follows: power, chemicals, operation and maintenance, and module replacement.

Power

The primary energy requirements for a reverse osmosis system are associated with the high-pressure pumps. Experience indicates that the ancillary equipment requirements (transfer pumps, booster pumps, chemical feeders, etc.) will add approximately 10% to this load.

Present systems are rated based upon nominal operation at 600 psi on the main pumps and a 75% recovery (i.e., 3 gal of product water for each 4 gal of feed). The modules are qualified at 800 psi, and the other system components are designed for pressures in excess of 1000 psi. At some time in the future, the standard operating pressure may become 800 psi. If that occurs, the power costs will be increased above those calculated below by one-third, but the initial module loading (and the capital cost) and the module replacement cost can be lowered below the values listed later for a net saving in both capital and operating costs.

Energy requirements at 600 psi and 75% recovery, assuming a combined pump/motor efficiency of 85%, may be calculated as follows:

$$\text{Pumping Power} = \frac{600 \times 7.28 \times 10^{-3}}{0.85 \times 0.75} = 6.85 \text{ kWh/1000 gal product}$$

$$\text{10\% Allowance for Auxiliaries} = \underline{0.68\qquad\qquad\qquad}$$

$$= 7.53 \text{ kWh/1000 gal product}$$

In order to arrive at a "cost," 1¢/kWh has been assumed.

Chemicals

Chemical treatment of the feedwater will require adjustment of the pH by acid addition to eliminate possible carbonate scaling and to improve module lifetime, the addition of a threshold treatment such as sodium hexametaphosphate to control sulfate scaling, and the addition of chlorine

to control organic sliming or fouling. Furthermore, it will be necessary to decarbonate and/or add caustic to the product water to restore its pH to near neutral, because at the recommended adjusted feedwater pH of from 5.0 to 6.0, the product water pH will also be low.

It is usually possible to avoid carbonate scaling by neutralizing approximately three-quarters of the bicarbonate alkalinity. On this basis, the cost of neutralizing 300 ppm bicarbonate alkalinity (as $CaCO_3$) using sulphuric acid will range downward from 9¢ to ∿7¢/1000 gal of feed.

Since sulfate scaling is a potential problem, the addition of 5 ppm sodium hexametaphosphate to the feedwater is recommended. This will cost approximately 0.75¢/1000 gal of feed.

Chlorination, to achieve a residual of 1/2 to 1 ppm, will be a trivial cost increment.

Since the product water must be neutralized, some means of CO_2 removal is desirable to reduce the costs incurred from caustic material. Without decarbonation, the neutralization of the product will cost approximately as much as the acidification of the feed. With decarbonation, it will cost about one-tenth that value. Decarbonation is strongly advised in Death Valley and would result in a significant cost savings compared with the estimate presented below.

Assuming operation at 75% recovery on a feedwater containing 350 ppm of bicarbonate alkalinity (as $CaCO_3$), the use of H_2SO_4 to acidify, the use of 5 ppm sodium hexametaphosphate to control sulfate scaling, a minimum requirement for chlorination, and the necessity for reneutralizing the product, chemical costs may be calculated as follows:

pH Adjustment	$\frac{7¢/1000}{0.75}$	= 9.4¢/1000 gal product
Threshold Treatment	$\frac{0.75¢/1000}{0.75}$	= 1.0¢/1000 gal product
Product Neutralization		= 9.4¢/1000 gal product
	Total	= 19.8¢/1000 gal product

Operation and Maintenance

Operating experience with reverse osmosis systems to date indicates that operating and maintenance labor requirements are minimal and that maintenance material requirements will be quite low. The 50,000-gpd reverse osmosis unit at the River Valley Golf Course operated essentially continuously for 2 yr in a locked building. Once each working day, specific performance data were taken to obtain detailed test information.

Based on what are considered to be realistic assumptions, the following operation and maintenance costs have been calculated. Water costs are based upon 330 operating days/yr.

	Unit Size (gpd)					
	10K	25K	50K	100K	250K	500K
Manpower @$10K/yr	1	1.25	2.5	3.3	5.0	6.7
Maint. Mtl. $K	0.22	0.50	0.8	1.3	2.4	3.9
Total $K/yr	1.22	1.75	3.3	4.6	7.4	10.6
¢/1000 gal	37	26	20	14	9	7

	Unit Size (gpd)			
	1000K	2500K	5000K	10,000K
Manpower @ $10K/yr	10	15	20	30
Maint. Mtl. $K	6.2	12.5	20	30
Total $K/yr	16.2	27.5	40	60
¢/1000 gal	5	4	3	2

Module Replacement

The contribution to water costs which results from module replacement depends upon the achievable module lifetime, the maintenance of membrane flux rates, and the price of replacement modules. Based on operating experience in the field, it is reasonable to assume a flux rate of 8.33 gal/ft^2-day at 600 psi over a 3-yr operating lifetime. Adjustment of the pH to a level of 5 to 6 should ensure that the salinity of the product water will not increase by more than a factor of 2 to 3 during 3 yr. Early in the operating lifetime, the system productivity will be higher and the product salinity will be lower.

Module replacement costs have been calculated based upon the above ground rules and the present price schedule. "Future" module replacement costs were also calculated by assuming that some combinations of lower prices, longer lifetimes, and higher module productivity would allow a factor of 2 reduction in module replacement costs. This is considered to be a realistic assumption for the 1971 time period.

Summary of Operating Costs

Operating costs, in ¢/1000 gal of product water, are summarized in Table 5. These data are based upon operation at 600 psi and 75% water recovery as well as the assumptions noted in the previous subsections.

CAPITAL COSTS

The largest reverse osmosis system in existence today is 125,000 gpd. However, it is possible to estimate the cost of much larger plants with little risk of error. Sufficient engineering design work has been performed, for example, to allow GGA to have bid fixed price on reverse osmosis plants up to 3 mgd.

Representative capital costs have been calculated for plants up to 10 mgd using present technology at 600-psi operation and using future

TABLE 5

OPERATING COST SUMMARY
(¢/1000 GAL PRODUCT)
600-PSI OPERATION AT 75% RECOVERY
77°F

Unit Size	Power	Chemicals	O&M[a]	Modules		Total	
				Present	Future	Present	Future
10K	7.5	19.8	37	30	15	94	79
25K	7.5	19.8	26	30	15	83	68
50K	7.5	19.8	20	30	15	77	62
100K	7.5	19.8	14	25	13	66	54
250K	7.5	19.8	9	25	13	61	49
500K	7.5	19.8	7	20	10	54	44
1,000K	7.5	19.8	5	20	10	52	42
2,500K	7.5	19.8	4	15	8	46	39
5,000K	7.5	19.8	3	15	8	45	38
10,000K	7.5	19.8	2	10	5	39	34

[a] Operation and maintenance

technology at 800-psi operation. These costs are presented in Table 6. They include the reverse osmosis unit (f.o.b. San Diego), a pretreatment skid which provides safety filtration for the pump (and modules), an automatic pH controller, a chemical feed pump, an acid feed pump and a booster pump, and a control system adequate for the commercial application of the appropriate unit. Essentially, each unit is considered to be a "black box" ready to plug into a buyer's facility, although clearly the larger units would be field-assembled in large measure. The figures given here are based upon operation of a feedwater at 77°F and include the fabricator's profit. Prices can be provided for different feedwater conditions upon request.

WATER COSTS

Water costs have been summarized using the data from Table 6. Table 7 summarizes typical water costs as a function of plant size for present and future technology, as defined previously.

TABLE 6

CAPITAL COSTS
77°F - 75% RECOVERY

Unit Size	Price (1000 $) Present[a]	Future[b]	Increment to Op. Cost (10% Annual Charge) (¢/1000 gal) Present[a]	Future[b]
10K	18	10	54	33
25K	32	18	38	27
50K	50	32	30	20
100K	92	61	27	18
250K	206	125	25	15
500K	325	203	19	11
1,000K	562	278	18	10.0
2,500K	1130	595	13	7.0
5,000K	1895	985	11	7.5
10,000K	3290	1700	10	6.0

[a] At 600 psi.

[b] At 800 psi.

TABLE 7

WATER COSTS (INCLUDING CAPITAL CHARGE AT 10%)
(¢/1000 GAL)
77^{o}F – 75% RECOVERY

Unit Size	Power	Chemicals	O&M[(a)]	Modules		Capital		Total	
				Present	Future	Present[(b)]	Future[(c)]	Present[(b)]	Future[(c)]
10K	7.5	19.8	37	30	15	54	33	148	112
25K	7.5	19.8	26	30	15	38	27	121	95
50K	7.5	19.8	20	30	15	30	20	107	78
100K	7.5	19.8	14	25	13	27	18	93	72
250K	7.5	19.8	9	25	13	25	15	86	64
500K	7.5	19.8	7	20	10	19	11	73	55
1,000K	7.5	19.8	5	20	10	18	10	70	52
2,500K	7.5	19.8	4	15	8	13	8.5	59	46
5,000K	7.5	19.8	3	15	8	11	7.0	56	45
10,000K	7.5	19.8	2	10	5	10	6.0	49	40

(a) Operation and maintenance

(b) For 600-psi operation

(c) For 800-psi operation

7. RECOMMENDATIONS

The field demonstrations conducted at both Furnace Creek and Stove Pipe Wells in Death Valley National Monument were highly successful. The results described in this report should leave no doubt that reverse osmosis is capable of converting the substandard spring and well water supplies in Death Valley into potable sources. Discussions of the requirements and economics of reverse osmosis have been presented to demonstrate the ease with which this process can be implemented and operated and the low cost of the water produced.

On the basis of the information now available, it appears that in the Village Park area of Furnace Creek a 200,000-gpd reverse osmosis unit would best supply the needs of the existing facility. Some of the important advantages of this unit would be:

1. Essentially no disturbance to ecological stability of the area
2. Elimination of travertine (calcium carbonate) precipitation on evaporative coolers, and consequent maintenance cost reduction
3. Reduction of fluoride content to within U.S. Public Health Service upper limit
4. No alteration required to existing plumbing system
5. Elimination of brine through existing waste disposal system after slight lagoon enlargement
6. Unit maintenance and operation consolidated to a single location and held to a minimum

The cost of water produced by a unit of this size is estimated to be 87¢/1000 gal. This figure includes the capital costs of the system hardware, operation and maintenance, chemical costs, power costs, and module replacement costs. As time elapses this cost can be expected to decline rather than increase.

The information gathered at Stove Pipe Wells indicates that a 50,000- to 70,000-gpd reverse osmosis unit would best supply the needs of that area. Some of the important advantages of this unit would be:

1. Essentially no disturbance to ecological stability of the area
2. Conversion of currently substandard well water into a readily available potable source
3. Elimination of necessity to import potable water
4. No alteration required to existing plumbing system, and outlets that are currently delivering undrinkable water would be delivering high-quality potable water
5. Elimination of brine easily accomplished by ponding
6. Unit maintenance and operation consolidated to a single location and held to a minimum

The cost of the water produced by a unit of this size is estimated to be $1.07/1000 gal. Again, this includes the capital costs of system hardware, operation and maintenance, chemical costs, power costs, and module replacement costs. With time, this cost also can be expected to decline.

If the recreational facilities in the Stove Pipe Wells area are expanded, the output of the reverse osmosis unit could be increased by the addition of more modules and a commensurate increase in the pump capacity. In this manner, enough potable water for the entire area would be provided from one central location.

From the results obtained during actual field demonstrations, it can be seen that reverse osmosis is a successful water treatment process. This technical success combined with the economic advantages of the process indicates that reverse osmosis deserves strong consideration as a realistic solution to the water treatment problems in Death Valley.

APPENDIX A

REVERSE OSMOSIS: A GENERAL DESCRIPTION

Osmosis can be defined as the spontaneous passage of a liquid from a dilute to a more concentrated solution across a semipermeable membrane. This membrane allows the passage of the solvent (water) but not the dissolved solids (solutes)(see Fig. 10). The transfer of the water from one side of the membrane to the other continues until the pressure is large enough to prevent any net transfer of the water to the more concentrated solution. At equilibrium, the quantity of water passing in either direction is equal, and the pressure is then defined as the osmotic pressure of the solution having that particular concentration of dissolved solids.

Reverse osmosis is a process achieved by placing a pressure on the concentrated solution (by means of a pump) sufficient to overcome the osmotic pressure. Thus, the water is driven from the more concentrated solution, through the semipermeable membrane, and into the less concentrated side (see Fig. 11).

The cellulose acetate semipermeable membrane used in almost all reverse osmosis systems acts as a highly effective barrier to the passage of dissolved and suspended substances. Gulf General Atomic reverse osmosis systems utilize a modified cellulose acetate membrane capable of rejecting up to 97.5% sodium chloride at 600 psi.

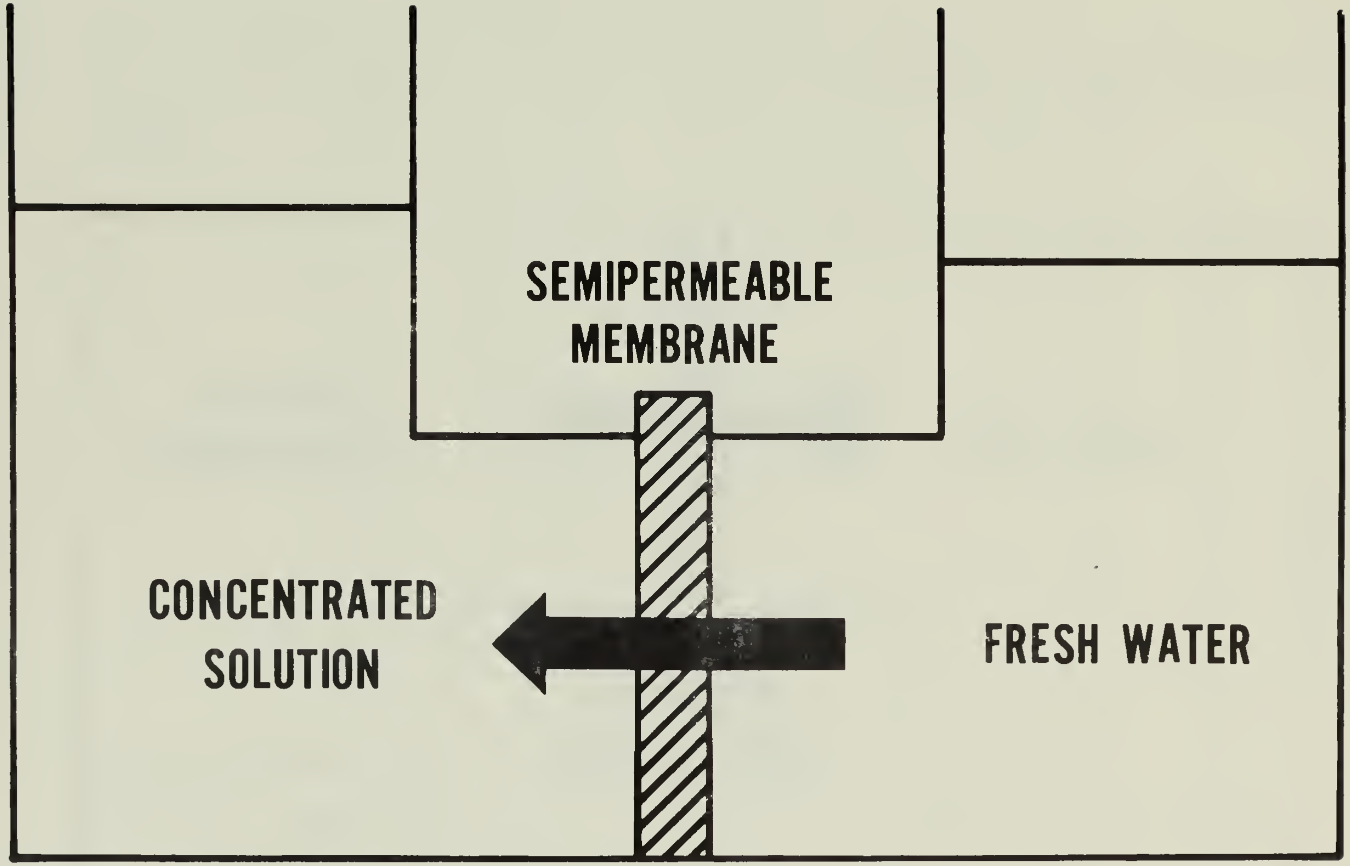

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Fig. 10. Osmosis: normal flow from low to high concentration

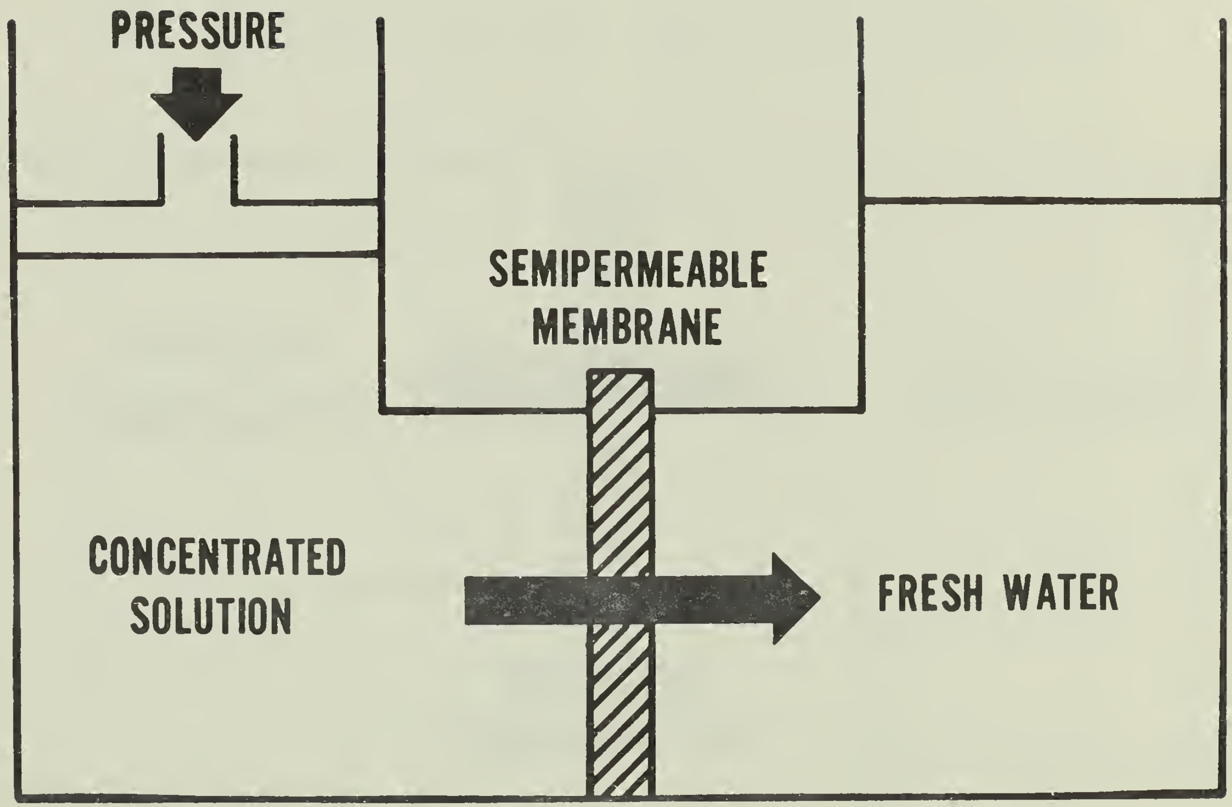

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Fig. 11. Reverse osmosis: flow reversed by application of pressure to high-concentration solution

APPENDIX B

U.S. PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS*

Chemical substances listed in Table 8 should not be present in a water supply in excess of the listed concentrations where, in the judgment of the Reporting Agency and the Certifying Authority, other more suitable supplies are, or can be, made available.

When fluoride is naturally present in drinking water, the concentration should not average more than the appropriate upper limit in Table 9. Presence of fluoride in average concentrations greater than two times the optimum values in Table 9 shall constitute grounds for rejection of the supply.

Where fluoridation (supplementation of fluoride in drinking water) is practiced, the average fluoride concentration shall be kept within the upper and lower control limits in Table 9.

Presence of the substances listed in Table 10 in excess of the concentrations listed shall constitute grounds for rejection of the supply.

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*U.S. Department of Health, Education, and Welfare, <u>Public Health Drinking Water Standards, 1962</u>, U.S. Government Printing Office, Washington, D.C., pp. 7 and 8.

TABLE 8

MAXIMUM CHEMICAL SUBSTANCE LIMITS

Substance	Concentration (mg/l)
Alkyl Benzene Sulfonate (ABS)	0. 5
Arsenic (As)	0. 01
Chloride (Cl)	250. 0
Copper (Cu)	1. 0
Carbon Chloroform Extract (CCE)	0. 2
Cyanide (CN)	0. 01
Fluoride (F)	(See Table 9)
Iron (Fe)	0. 3
Manganese (Mn)	0. 05
Nitrate (NO_3)	45. 0
Phenols	0. 001
Sulfate (SO_4)	250. 0
Total Dissolved Solids	500. 0
Zinc (Zn)	5. 0

TABLE 9

FLUORIDE LIMITS

Annual Average of Maximum Daily Air Temperatures (°F)	Recommended Control Limits, Fluoride Concentrations (mg/l)		
	Lower	Optimum	Upper
50.0 to 53.7	0.9	1.2	1.7
53.8 to 58.3	0.8	1.1	1.5
58.4 to 63.8	0.8	1.0	1.3
63.9 to 70.6	0.7	0.9	1.2
70.7 to 79.2	0.7	0.8	1.0
79.3 to 90.5	0.6	0.7	0.8

reject at

TABLE 10

MAXIMUM SUBSTANCE LIMITS

Substance	Limit (mg/l)
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Hexavalent) (Cr^{+6})	0.05
Cyanide (CN)	0.2
Fluoride (F)	(See Table 9)
Lead (Pb)	0.05
Selenium (Se)	0.01
Silver (Ag)	0.05